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Analysis of stable water isotopes in tropospheric moisture during the West African Monsoon

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Three-dimensional distributions of atmospheric moisture with high spatial and temporal variability arise from the complex interaction of the various branches in the hydrological cycle. By studying abundances of stable water isotopes, one can retrieve fundamental information about the physical processes acting in these branches. Differences in the molecular structure lead to characteristic responses of each water isotope to phase change processes, which reflects on characteristic ratios of water isotopes in different branches of the hydrological cycle.

In this study, we use tropospheric distributions of H_2O and HDO (denoted as δD) to identify dominant processes in the hydrological cycle during the wet phase of the West African Monsoon in boreal summer. Here, large gradients in water vapor, strong convective activity and continental recycling lead to high variability of tropospheric moisture and its isotopic composition. This complexity makes a direct attribution of observed water vapor signals to underlying processes challenging.

To address this challenge, we use remotely sensed {H_2O, δD} – pair data retrieved from spectra of the thermal infrared satellite sensor IASI, which are available daily and globally from October 2014 to June 2019. For an improved understanding of the IASI data, we add high-resolution model data from the regional isotope-enabled model COSMO-iso and generate Lagrangian backward trajectories for the Sahelian troposphere. This provides valuable insights into geometrical and moisture pathways along the history of Sahelian air masses that were observed from IASI. Further, after applying a retrieval simulator on the COSMO-iso data, we can conduct direct satellite-to-model comparisons.
By drawing these datasets together, we document and analyze the characteristic variability of the {H_2O, δD} – pairs for the Sahelian troposphere on interannual, seasonal and convective scales. We identify distinct effects on {H_2O, δD} – pairs of (1) synoptic-scale and boundary air mass mixing, (2) rain condensation during convection and (3) partial evaporation and isotope equilibration of rain drops during convection.

This study reveals the potential of using MUSICA IASI {H_2O, δD} – pair data together with high-resolution modeling for investigating the tropospheric hydrological cycle. This approach is promising for understanding the relative importance of large-scale dynamics against microphysical phase transitions during convection on the tropical moisture distribution.